Development of a 2K x 2K GaAs QWIP focal plane array

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ABSTRACT

We are developing the next generation of GaAs Quantum Well Infrared Photodetector (QWIP) focal plane arrays (FPAs) in preparation for future NASA space-borne Earth observing missions. It is anticipated that these missions will require both wider ground spatial coverage as well as higher ground imaging resolution. In order to demonstrate our capability in meeting these future goals we have taken a two-tiered approach in the next stage of advanced QWIP focal plane array development. We will describe our progress in the development of a 512 x 3,200 (512 x 3K) array format for this next generation thermal imaging array for the NASA Landsat project. However, there currently is no existing readout integrated circuit (ROIC) for this format array so to demonstrate the ability to scale-up an existing ROIC we developed a 1,920 x 2,048 (2K x 2K) array and it hybridized to a Raytheon SB419 CTIA readout integrated circuit that was scaled up from their existing 512 x 640 SB339 ROIC. Two versions of the 512 x 3K QWIP array were fabricated to accommodate a future design scale-up of both the Indigo 9803 ROIC based on a 25 µm pixel dimension and a scale up of the Indigo 9705 ROIC based on a 30 µm pixel dimension. Neither readout for the 512 x 3K has yet to be developed but we have fabricated both versions of the array. We describe the design, development and test results of this effort as well as the specific applications these FPAs are intended to address.

1. INTRODUCTION

In anticipation of potential future Earth observing ground-based, airborne and space applications we are developing unique, larger format GaAs QWIP arrays. In collaboration with the Army Research Laboratory we have fabricated three large format GaAs QWIP arrays: a 512 x 3,200 (512 x 3K) array with 30 µm square pixels; a 512 x 3,200 (512 x 3K) array with 25 µm square pixels; and a 1,920 x 2,048 (2K x 2K) GaAs QWIP array with 20 x 20 µm pixels. However, ROICs for either of the 512 x 3K arrays do not currently exist (and the development costs associated with scaling up existing ROICs far exceeded the scope of this project). Therefore we chose a path that would demonstrate all aspects of the development of these focal plane arrays in a piecemeal fashion that would prove our capability and eliminate almost all risk once the project is funded in the future. To this end, we fabricated all three large format QWIP arrays, verified their performance using 640 x 512 test arrays (fabricated on the same GaAs wafer), scaled up an existing 512 x 640 ROIC (at minimal cost) to a 1,920 x 2,048 ROIC and hybridized the QWIP array to this Raytheon Vision Systems (RVS) SB419 ROIC. Each of these arrays is intended to solve different science and technology problems. The 2K array will ultimately be integrated into a portable camera to improve our field of view and spatial resolution for ground based imaging in the Mojave desert and other locations currently being considered in collaboration with the US Geological Survey in their study of caves, specifically remotely locating cave entrances (on mars, for example). The 512 x 3K array fabrication proved the feasibility of array development for a potential future NASA high-resolution, wide swath, thermal IR imager aboard an orbiting Landsat satellite platform. The successful scale-up of the RVS ROIC and hybridization subsequent hybridization demonstrated the feasibility of implementing existing designs and technology to meet the needs of very large format arrays.

Current Landsat IR imaging requirements provide a ground resolution of $100m^2$ on a $25\ \mu m^2$ pixel from a 700 km orbit. Each sample frame covers a ground swath 100 meters wide by 185 km long. It is desirable to increase the ground resolution to 60 meters. This translates to equivalently 3,084, $25\ \mu m^2$ pixels in a slower (longer focal length) optical system or equivalently the same $100m^2$/pixel resolution with a ground swath of 320 km with the current Landsat Thermal IR Sensor (TIRS) optical system. In the recently developed TIRS instrument imaging was performed in a push

bump bonder (SET FC150) is only capable of applying a maximum of 100 kgs of force that is about half the force that would be optimum. Knowing this in advance we anticipated excess pixels that would be non-responsive (not electrically connected to the ROIC). The assembled unit is shown in figure 4. The QWIP hybrid is *temporarily* attached to the silicon substrate with a layer of thermal grease on the underside of the QWIP hybrid and then tacked down along top edge with dots of Dow 280A adhesive. We intend to build a portable camera system around this array. Therefore, the QWIP hybrid must be removed from the silicon substrate and subsequently remounted in a different configuration.

15000Å	GaAs	$1.1 \times 10^{18}\ cm^{-3}$	
50Å	AlGaAs (x = 0.169)	undoped	
19Å	GaAs	undoped	
31Å	GaAs	$1.1 \times 10^{18}\ cm^{-3}$	
5Å	GaAs	undoped	x 60
700Å	AlGaAs (x = 0.169)	undoped	
19Å	GaAs	undoped	
31Å	GaAs	$1.1 \times 10^{18}\ cm^{-3}$	
5Å	GaAs	undoped	
50Å	AlGaAs (x = 0.169)	undoped	
35000Å	GaAs	$1.1 \times 10^{18}\ cm^{-3}$	
1000Å	AlGaAs (x = 0.3)	undoped	
2500Å	GaAs	undoped	
	GaAs	S.I. - SUBSTRATE	

Figure 2. The C-QWIP epitaxial structure for the 2K x 2K and 512 x 3K (and test arrays).

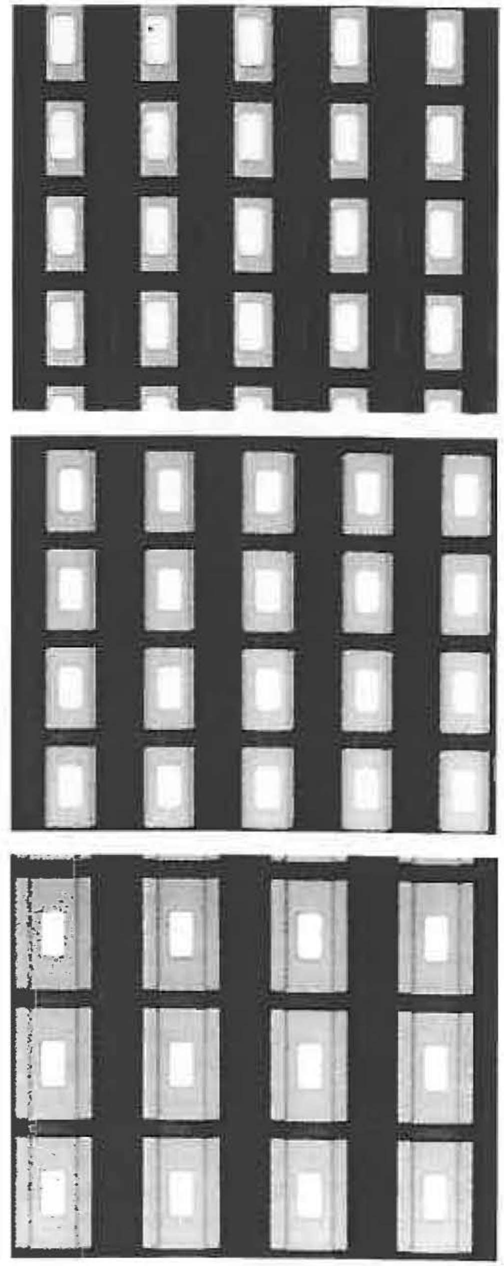

Figure 3. Pixel photographs of each of the three QWIP arrays. Top; 20 μm pixels of the 2K array. Middle; 25 μm pixels and: Bottom; 30 μm pixels each from a 512 x 3K array. Each image is 1000x magnification.

3. TEST AND PERFORMANCE RESULTS

Testing this hybrid presented some challenges that we do not regularly encounter with our smaller format (up to 1K x 1K) arrays. Commercially available optics that has an image focal plane diameter of 57 mm necessary to fully illuminate this detector array are not readily available. Custom fabrication of such a lens system proved to be too costly for this project as well, so we improvised with some of our existing optics. Real time video display was not available so imaging became somewhat tedious in that raw data was collected and then post-processed to obtain an image. The ability to fabricate very large QWIP FPAs turns out to be a double-edged sword. It is relatively

TABLE 1. Characteristics of the RVS SB419

Array Format	1,920 x 2,048
Pixel size	20 µm x 20 µm
Number of video outputs	6/12
Full well capacity	2.5M electrons (low gain); 70K electrons (high gain)
High gain node sensitivity	32.4 µV/e-
Low gain node sensitivity	0.72 µV/e-
Pixel rate	5.5 MHz/channel
Frame Rate	~16 fps (12 outputs)
Readout Noise	500 electrons (low gain); 120 electrons (high gain)
Integration time	30 µs to 30 ms (full array)
Linearity	≤2% (10-90%)
V_{detcom}	2.9 v
Power dissipation	120-180 mW (low gain); 500-560 mW (high gain)

Once convinced that the QWIP wafer fabrication yielded high quality arrays we hybridized a 2K x 2K array (we have only a few 2K x 2K ROICs so we proceeded quite gingerly) to an RVS ROIC and performed some imaging experiments. We did not repeat the dark current or CE tests but did perform an overall pixel yield tabulation. Approximately 11.7% of the pixels (~ 460,000) either were not connected or so weakly connected as to barely have any response. A 293 K and 320 K flat field image is shown below in figure 6. Both flat field sources were integrated for 5.0 ms and the detector temperature was approximately 40 K with a bias of 3.0 volts. We found the ROIC to exhibit some non-linearities of unknown origin. The output signal in digital numbers as a function of the integration time is shown in figure 7. There appears to be a threshold below which no signal is detected. For a 3 ms integration we would expect an integrated dark signal to be about 150,000 electrons based on the QWIP/9803 hybrid data. Yet the linearity curve is still flat indicating either no signal is present or a threshold needs to be reached before signal is integrated by the ROIC. It is also entirely possible that this may be an anomaly associated with this particular ROIC unit.

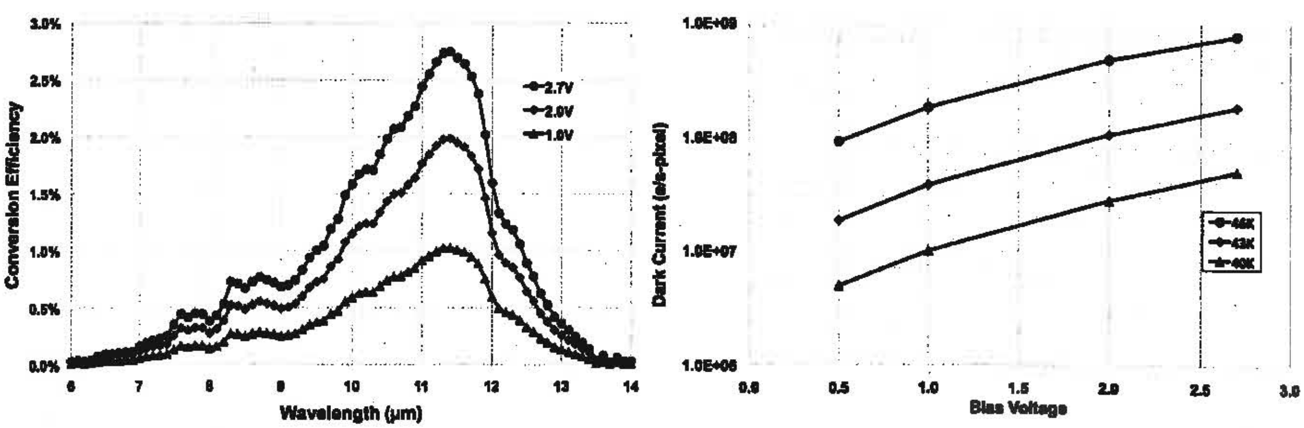

Figure 5. Conversion efficiency (left) and dark current (right) plots of the C-QWIP array hybridized to an Indigo 9803 ROIC. This array was one of the four test die on the 2K x 2K wafer shown in figure 1.

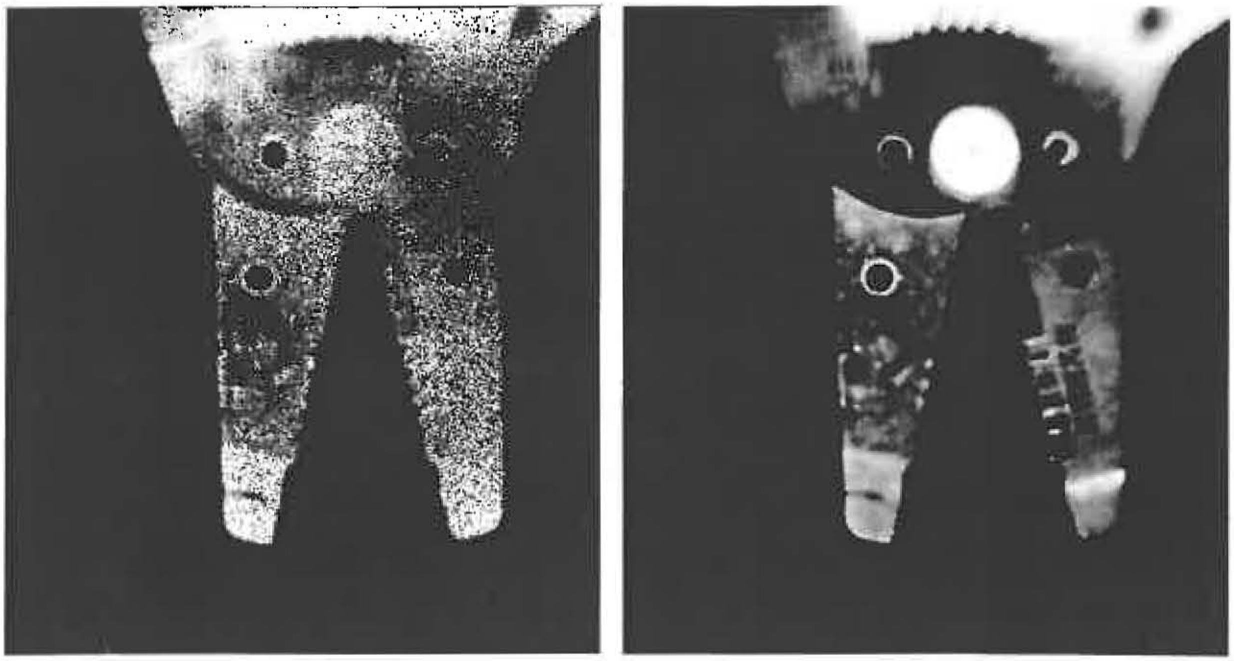

Figure 8. Image acquired by the 2K x 2K array in dewar configuration at 40 K. Left; 300 K background-subtracted image. Right; Two point correction and post processing of same image field.

4. CONCLUSION

This effort has demonstrated a number of technical accomplishments as well as bringing to the forefront limitations and challenges facing the future development of very large format QWIP arrays. First and foremost we have demonstrated the development and operation of (we believe) the first 2K x 2K, 8-12 μm QWIP imaging array. We encountered numerous technical obstacles that are essentially unrelated to the actual GaAs QWIP array fabrication and this highlights one of the historically advertised advantages of QWIP arrays: they are relatively easy to fabricate in any format that is desired. However, the limitations that arise with this evolutionary scaling upwards become quite apparent. The first is the diameter of the GaAs wafer. We were able to incorporate two 2K arrays on a single 100mm diameter wafer. However, for future NASA missions, array lengths exceeding 3,500 pixels is under consideration and these barely fit (depending on the pixel dimension) on a 100 mm diameter wafer. The next obstacle is the need for custom ROICs to accommodate the large formats and the large full well (>2Me-) requirements of high background applications (given the current conversion efficiencies QWIP devices exhibit). The costs associated with developing an advanced custom ROIC can easily exceed $1M. Another technological limitation for our group was the maximum force we could apply to the hybrid during our indium bump bonding process. We managed to successfully connect most of the pixels but not nearly enough for a high performance application. Finally, to take full advantage of the large field-of-view a customized optical system needs to be developed, specifically a LWIR lens capable of producing a ~60 mm image diameter at the focal plane. In spite of these shortcomings, all the risk has been relegated to entirely solvable problems that require only funding and no risky technology developments. We have demonstrated the fabrication and performance of the required large format arrays for the next generation of Earth observing satellites and the timely and compatible scale-up of existing ROICs.